

CHAPTER 7

BRACED FRAMES

7-1. Introduction. This chapter prescribes the criteria for the design of vertical braced frames in seismic areas, indicates principles and factors governing the design, and illustrates typical details of construction.

7-2. General.

a. Function. Vertical braced frames are used to transmit lateral forces from the diaphragm above to the diaphragm below or to the foundations. They are similar to shear walls in their general function and their stiffness compared to the other type of vertical element, the moment resisting frame.

b. Definition of braced frame. In SEAOC 1B, a braced frame is defined as an essentially vertical truss system of the concentric or eccentric type that is provided to resist lateral forces. Note that for braced frames, as for shear walls, the R_w -value depends on whether the frame is in a bearing-wall or building-frame system.

c. Redundancy. A sufficient number of braced frames should be provided so that a failure of a single member or connection will not result in instability of the entire lateral force resisting system.

d. Braced frame types. The principal types of braced frame are the familiar concentric braced frame (CBF), the relatively new eccentric braced frame (EBF), and the knee-braced frame (KBF).

e. Design criteria. The criteria governing the design of vertical braced frames will be as prescribed in this chapter.

(1) *Structural steel braced frames.* Structural steel braced frames will conform to the requirements of SEAOC 4G for concentric braced frames and SEAOC 4H for eccentric braced frames.

(2) *Reinforced-concrete braced frames.* Concentric braced frames, permitted only in Zones 1 and 2, will conform to the requirements of ACI 21.5. No procedures have been developed for eccentric braced frames of reinforced concrete, because such frames would not be likely to demonstrate desirable performance.

(3) *Wood braced frames.* Wood braced frames will be designed by using normal procedures illustrated in many easily obtainable texts and are not covered in this manual. The National Forest Products Association's *National Design Specification for Wood Construction* applies.

7-3. Concentric braced frames (CBF).

a. Eccentricities. Although the frame is called "concentric", there may be minor eccentricities between member centerlines at the joints, and these eccentricities are provided for in the design. Such eccentricities do not mean that the frame is an EBF: the EBF has unique properties and design methods.

b. Concentric braced frame types. Frames are usually of steel and may be of various forms. The X-braced panels, consisting of diagonal tension members and vertical compression members, are frequently used (fig 7-1, part a). Trussed portal bracing or K-bracing is frequently used to permit unobstructed openings (fig 7-1, part b). See restrictions in SEAOC 4G3b. Braced frames with single diagonal members capable of taking compression as well as tension are used to permit flexibility in the location of openings (fig 7-1, part c). See restrictions in SEAOC 4G1c. Chevron bracing is also a common system for buildings (fig 7-1, part d and fig 7-2). The deflection of braced frames is readily computed using recognized methods.

c. Materials. CBFs are usually made of steel. There are no SEAOC provisions for concrete frames; in fact, CBFs of concrete are not permitted in Zones 3 and 4 (SEAOC Table 1-G).

d. Direction of brace force. Braces that are designed for compression will, of course, act also in tension. Braces may be designed for tension only, but the use of such braces is discouraged because they tend to stretch under earthquake tension, then go slack during the load reversal, then snap when tension is applied in a subsequent cycle. SEAOC requires a minimum slenderness ratio (SEAOC 4G1a) with certain exceptions for manufactured metal buildings and nonbuilding structures.

e. Effect of bracing on columns. The vertical component of brace force is transferred into the column and adds to the gravity load on the column. When brace forces are relatively small and the column design is governed by the gravity loads, the frame should be considered a building system, using R_w of 8 as prescribed in SEAOC Table 1-G. When braces are few and heavily loaded, their vertical components may govern the design of the columns. In such cases the frame should be considered a bearing wall system, using smaller R_w -factors as given in SEAOC Table 1-G. The concern with braces of the bearing wall category is that their true, as-built ultimate capac-

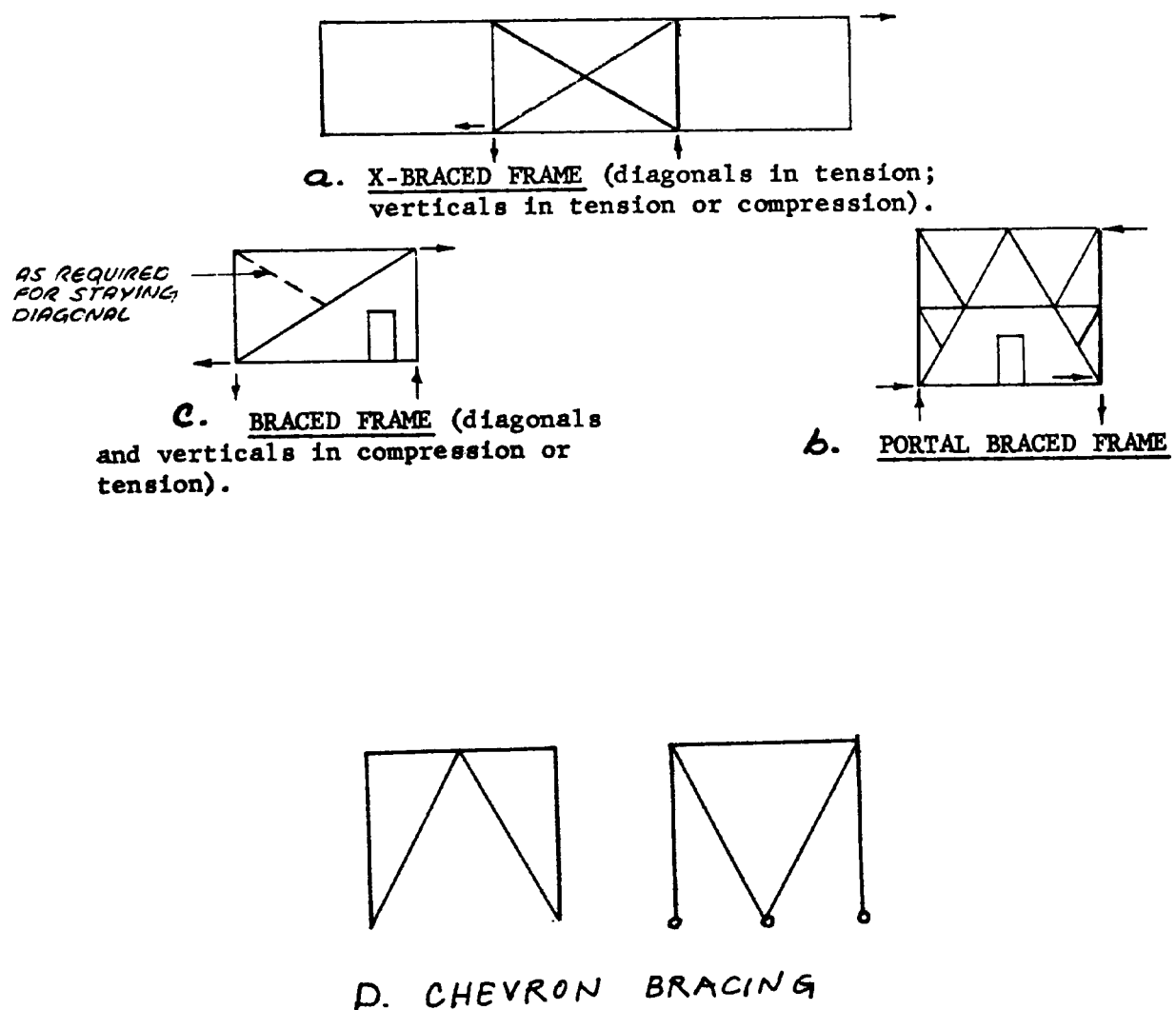


Figure 7-1. Braced frames.

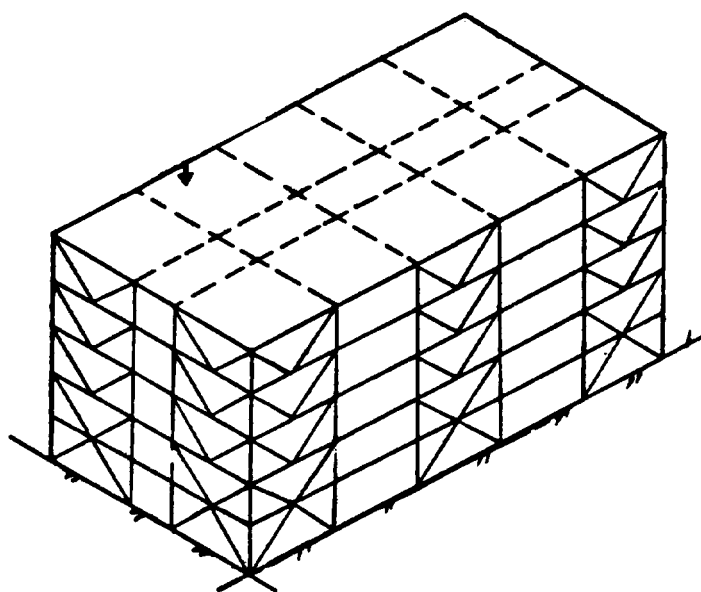


Figure 7-2. Bracing for a tier building.

ity may be greater than is assumed in design, and, therefore, that such braces could overload the column to the point of collapse.

f. Configurations. Diagonal X-bracing is common in tension-only bracing. Single diagonal braces are more common in compression-tension bracing. The orientation of single braces should be alternated so that not all of the braces are in tension or compression at the same time (SEAOC 4G1c). Chevron bracing may have an interaction with gravity load carrying beams; accordingly, special requirements are provided in SEAOC 4G3a. K-bracing has a potentially dangerous effect on columns; accordingly, it is subject to the requirements of SEAOC 4G3b.

g. Connections. SEAOC 4G2 provides the requirements for design of connections.

h. Low buildings. SEAOC 4G4 provides for buildings not over two stories and for light roof structures such as penthouses. Manufactured metal buildings are intended to be included in this category. In planning the use of manufactured metal buildings, the designer is cautioned that these buildings can perform well only when they are kept light and simple, as they are intended to be; they may have poor performance if extra weight, such as

masonry veneer, is added, or if they are used as elements of a more complex system.

7-4. Eccentric braced steel frames (EBF).

a. Definition. An EBF is a steel braced frame designed in accordance with SEAOC 4H. At least one end of each brace intersects a beam at a point offset from the beam intersection with the column or with the opposing brace (see fig 7-3). The short section of the beam between opposing braces, or between a brace and the beam-column intersection, is called the "link beam" and is the element of the frame intended to provide inelastic cyclic yielding.

b. Purpose. The intent of the eccentric braced frame design is to provide a ductile link which will yield in lieu of buckling of its braces when the frame experiences dynamic loads in excess of its elastic strength. Although they are usually easier to detail, they are more complex to design than CBFs, and they are most useful in Zones 3 and 4.

c. Characteristics. To take advantage of the ductility of the link, it is important that all related framing elements be strong enough to force the link to yield and that they maintain their integrity through the range of forces and displacements

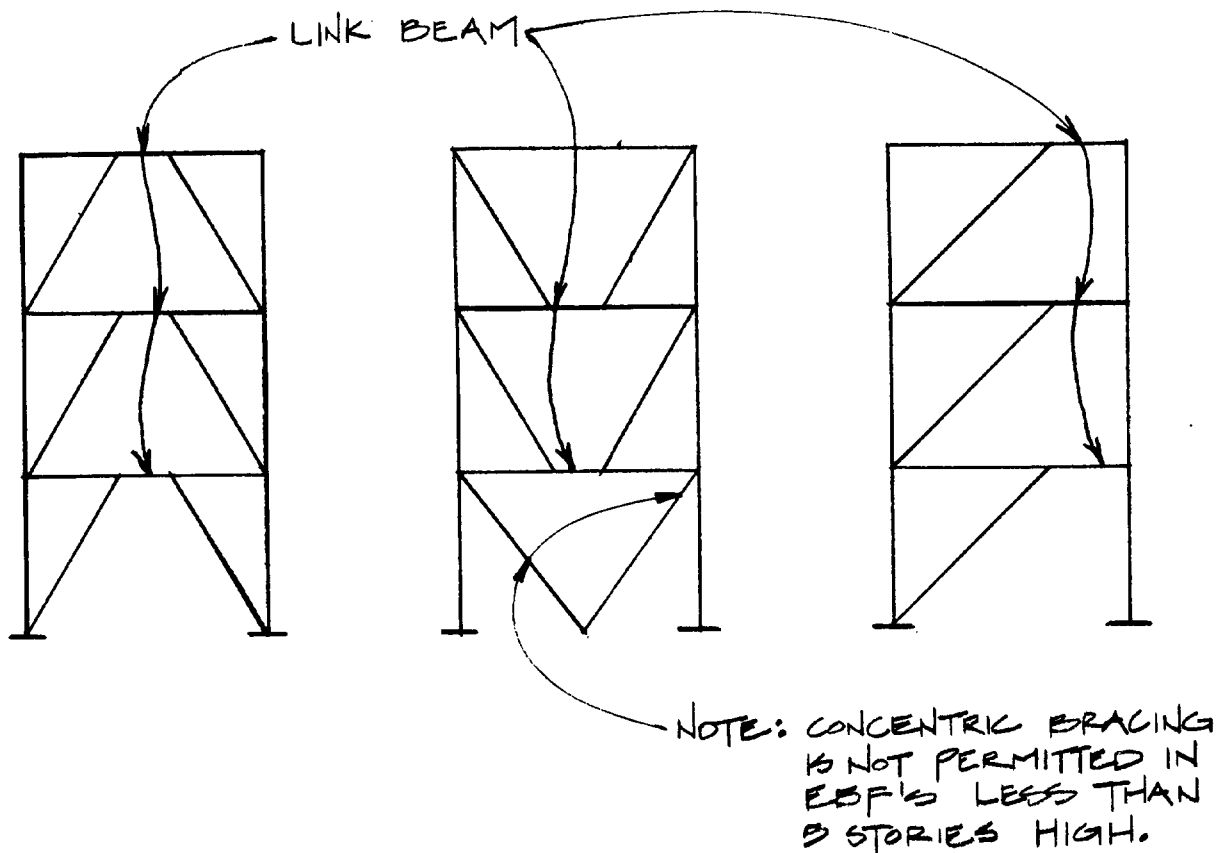


Figure 7-3. Eccentric braced frame configurations.

developed during the yielding of the link. The braces are the most vulnerable of the framing elements because seismic forces are by far the dominant forces in their design. Other elements, such as columns and collector beams, are less vulnerable, since their seismic loads constitute a smaller percentage of their total loads and since, frequently, there are redundant load paths for portions of the forces they carry. The rotation demand on the link beam is a multiple of the lateral drift of the frame as a whole, a multiple that is a function of the geometry of the frame (see figure 7-4). Link beams can yield in shear, in bending, or in both shear and bending at the same time. Which yield mechanism governs is a function of the relationship of link length to the ratio of its bending strength to shear strength. Where the length of the link beam is less than $1.6 M_s/V_s$, the yielding is almost entirely in shear. Where the length is greater than $2.6 M_s/V_s$, the yielding is primarily in bending. Where the length is between $1.6 M_s/V_s$ and $2.6 M_s/V_s$, both shear and bending yield will occur. Since link beams that yield in shear are considered to have the most stable energy dissipating characteristics, most of the EBF research has tested the cyclic inelastic capacity of link beams with shear yielding at large rotations. Consequently, most of the design provisions are concerned with limiting the link beam shear yield rotation to less than the maximum cyclic test rotations and then requiring details indicated by the tests as necessary to ensure that this rotation can occur through a number of cycles without failure.

d. Design criteria. The specific criteria governing the design of eccentrically braced frames is given in SEAOC 4H. It is explained in more detail below.

(1) *Link beam location and stability.* Link beams are the fuses of the EBF structural system and are to be placed at locations that will preclude buckling of the braces. A link beam must be located in the intersecting beam at least at one end of each brace. There are exceptions permitting concentric bracing at the roof level and/or at the bottom level of EBF over five stories in SEAOC 4H14 and 4H15. Compact sections meeting the more restrictive flange-width-to-thickness ratio of $52\sqrt{F_y}$ are required for the beam portions of eccentric braced frames in order to provide the beams with stable inelastic deformation characteristics. The same requirement is used for the beams of special moment resisting space frames.

(2) *Link beam strength.* The basic requirement for link beam strength is given in SEAOC 4H4, which requires that the shear in the link beam web

due to prescribed seismic forces be limited to $0.8 V_s$. Paragraph 4H2 addresses the concern for the effect that substantial axial loads in the link beam could have on its inelastic deflection performance. It presumes that in shear links the web's capacity is fully utilized in shear and that flanges provide the needed axial and flexural capacity. Shear links with a length less than $2.2 M_s/V_s$ are considered to be controlled by shear. Substantial axial loads occur in some EBF configurations when the link beam is required to transmit horizontal forces to or from the braces. It is recommended that, insofar as it is possible, link beams be located so that they are not required to transmit the horizontal force component of braces or drag struts. Where axial forces in the link cannot be avoided, SEAOC 4H2b requires that the flexural strength used in calculations in SEAOC 4H7 and 4H12 be reduced by the axial stress giving $M_{RS} = Z(F_y - f_a)$. The f_a used in SEAOC 4H2b should correspond to the lesser value of the axial force corresponding to yield of the link beam in shear, or that which, when combined with link bending, causes the beam flanges to yield.

(3) *Link beam rotation.* The link beam rotation, at a frame drift of $3/8 R_w$ times the drift calculated from prescribed seismic forces, is limited to the values given in SEAOC 4H3. The procedure for calculating the rotations is as follows (refer to fig 7-4):

(a) Perform an elastic analysis of the frame for the prescribed seismic forces, being certain that the analysis includes the contribution of the elastic shear deformation of the link beam.

(b) Calculate $3/8 R_w$ times the drift angle obtained from the analysis in (a). This angle is denoted as δ in figure 7-4.

(c) Calculate the rotation angle Θ , as shown in figure 7-4, for the appropriate configuration. This simplified procedure is slightly conservative, since the elastic curvature of the beam segments between hinges and of the brace deformations have been ignored and would contribute a minor amount of the required deformation. It should be noted that calculation of the rotation by multiplying the elastic deflections of the link beam by $3(R_w/8)$ would be unconservative, since these deflections include elastic effects, such as the axial deformation of the braces, that would not increase proportionally after the link begins to yield.

(4) *Link beam web.* Link beam web doubler plates are prohibited in SEAOC 4H4 because tests have shown that they are not fully effective. The performance of eccentric braced frames relies on the predictability of the strength and strain characteristics of the link beam. It is not considered

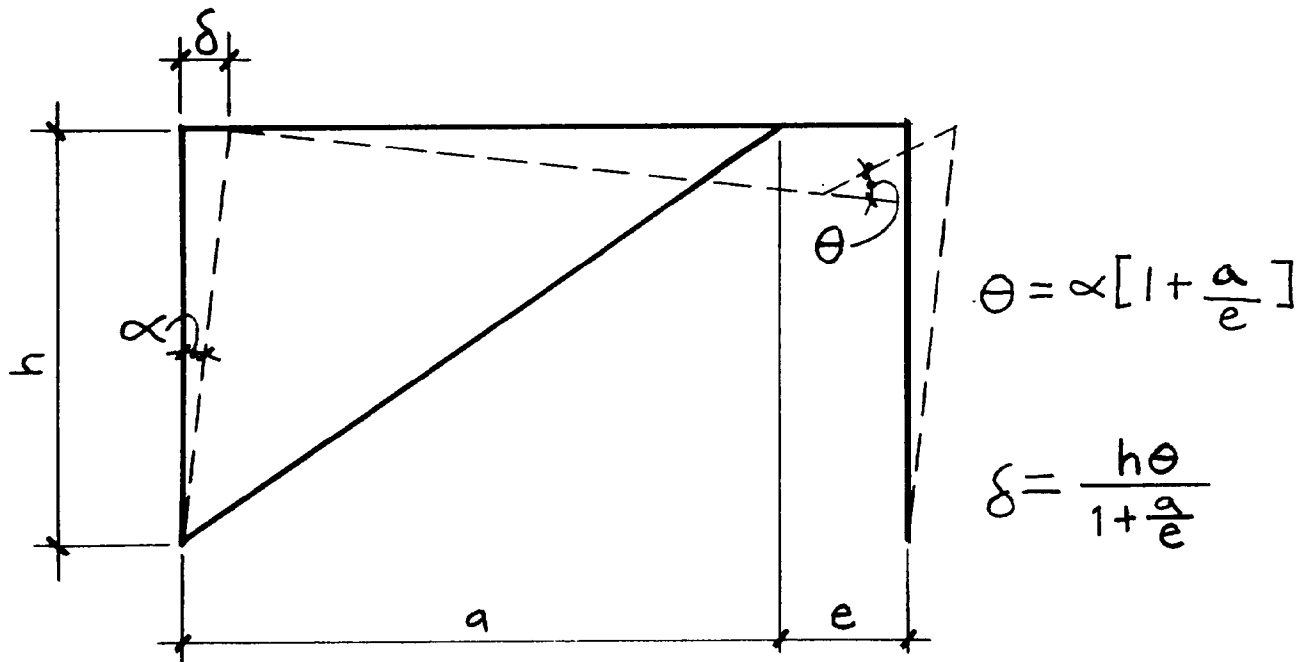
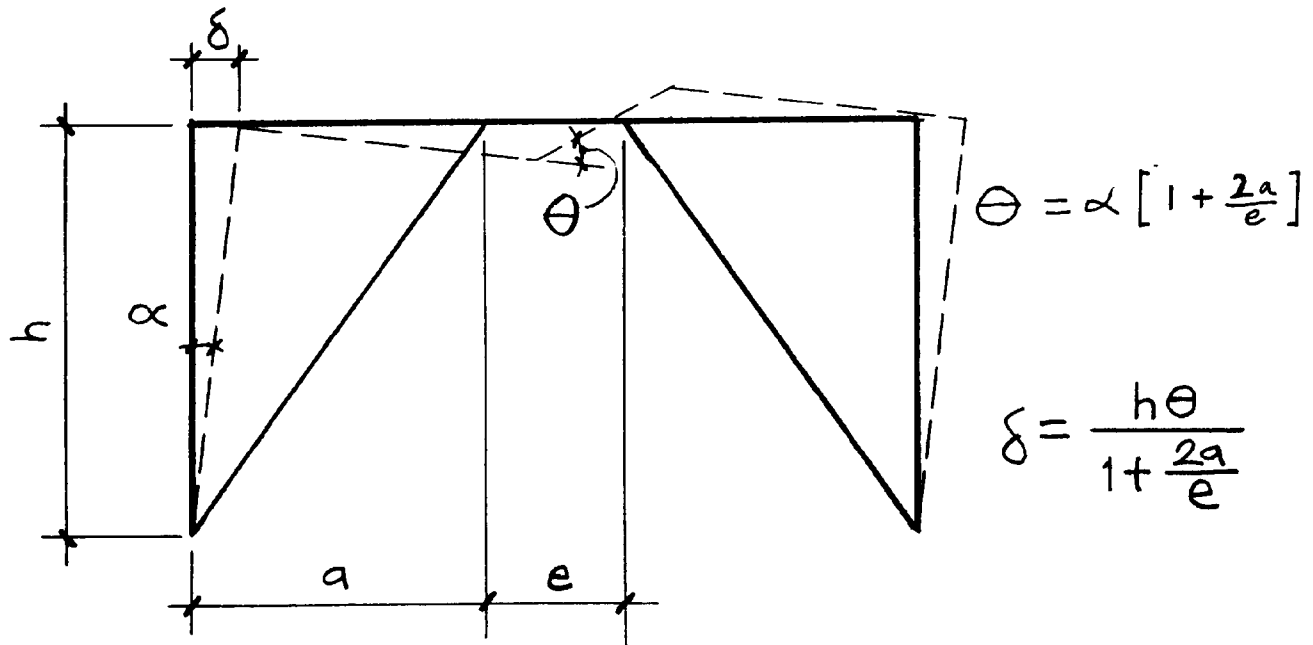


Figure 7-4. Deformed-frame geometry.

advisable to complicate the behavior of the link beam by permitting doublers or allowing holes within it.

(5) *Brace sizing.* Once the link beam size has been selected, the brace size is determined by the requirement given in SEAOC 4H12 that its compressive strength be at least 1.5 times the axial force

corresponding to the controlling strength of the link beam. The controlling strength is either the shear strength V_s or the reduced flexural strength M_{RS} described above, whichever results in the lesser force in the brace. Note that once the link beam is selected, the brace forces are determined from its strength, and the brace forces calculated in the

elastic analysis will not govern and will not be used in the brace design.

(6) *Brace-to-beam connection.* SEAOC 4H5 requires that the brace-to-beam connection develop the compressive strength of the brace and that no part of the brace-to-beam connection extend into the web area of the link. The required development may be at the strength level of the connection. The prohibition of the extension of the brace-to-beam connection into the link beam is intended to prevent physical attachments that might alter the strength and deflection characteristics of the link beam. It is not intended to prevent the centerline intersection of brace and link beam from intersecting within the link.

(7) *Column sizing.* SEAOC 4H13 requires that the columns remain elastic at 1.25 times the forces causing yield of the link beam. "Remain elastic at" means the same as "have the strength to resist." The strength, including bending moments, can be calculated using Part 2 of AISC.

(8) *Beam-to-column connections.* For link beams that are adjacent to a column, special connection criteria are given in SEAOC 4H11. Where the link beam is not adjacent to the column, a simpler criterion for connection is given in

SEAOC 4H18. Where the simpler connections are used, consideration must be given to transmission of collector forces into the EBF bay.

(9) *Intermediate stiffeners.* SEAOC paragraphs 4H6 through 4H10 provide requirements for various types of stiffeners necessary for the intended performance of the link beams. Stiffener plates as described in those paragraphs are required at the following locations (see fig 7-5):

(a) At the brace end(s) of the link beam (SEAOC 4H6)

(b) At b_f from each end where link beam length is between 1.6 M_s/V_s and 2.6 M_s/V_s (SEAOC 4H6).

(c) At intermediate points along the link beam where shear stresses control or are high (SEAOC 4H7, 4H8).

7-5. Knee-braced frames (KBF).

a. *Definition.* A KBF is an assembly of a beam, a column, and a brace whose ends are significantly offset from the beam-column joints. The braces in CBFs are either truly concentric or have small eccentricities with the beam-column joints; accord-

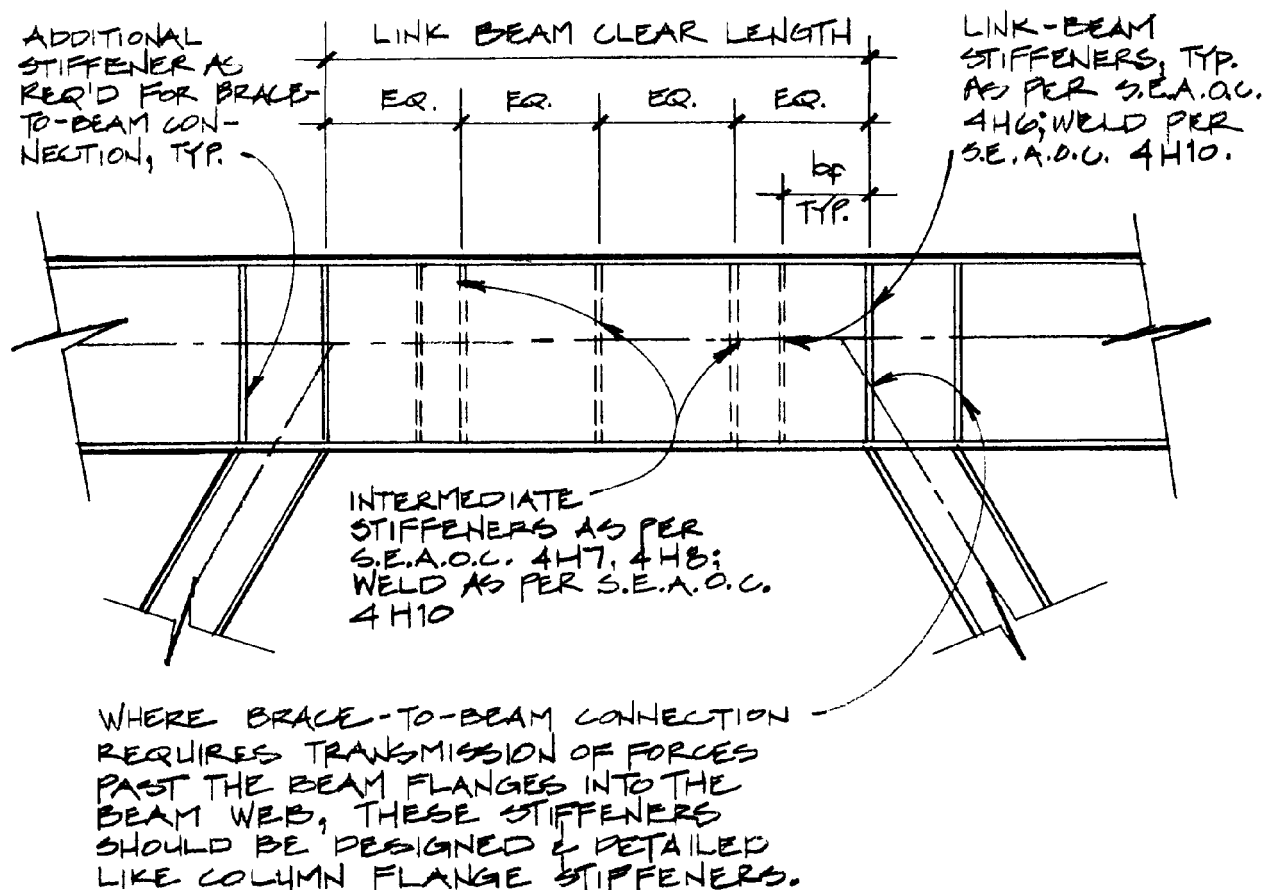


Figure 7-5. Link beam and intermediate stiffeners.

ingly, they induce forces that are primarily axial, while the braces in KBFs have substantial eccentricities and induce significant shearing and flexural as well as axial stresses in the columns and beams.

b. Function. Knee braces were often used in the past to stiffen beams and to provide a measure of lateral stability. Their popularity in recent years has decreased markedly, particularly in zones of high seismicity, because their seismic behavior has become recognized as potentially dangerous.

c. Design considerations. There are two concerns with KBFs. The first concern involves gravity load: any change in the load on the beam after the brace is connected induces forces in all the components of the frame; moreover, the brace has a prying effect that can produce surprisingly large forces in the beam-column joint. The sequence of erection and the further application of superimposed loads must be carefully controlled. The second concern involves seismic loads: another set of loads is applied, and while the brace does stiffen the frame, its as-built ultimate capacity may be sufficient to cause bending in the column of suffi-

cient magnitude to cause collapse.

d. Design criteria. KBFs should be designed with R_w value of 6. Steel KBFs are envisioned in the opening statement of SEAOC 4G, which says that 4G applies to all braced frames except EBFs and also says that members that resist seismic forces totally or partially by shear or flexure shall be designed in accordance with SEAOC 4F (SMRFs). Members of KBFs will be governed by SEAOC 4G1; connections, by SEAOC 4G2. The additional requirements of SEAOC 4F are provided in recognition of the fact that the KBF resembles the moment frame in that the braced corner of the KBF is analagous to the beam-column joint in the moment frame. In the KBF, the beam-column joint need not have moment capacity if it qualifies under the exception in SEAOC 4F1a(2). Other detailed provisions of SEAOC 4F offer relief from the SMRF requirements when design forces are increased, as is the case when the low R_w factors for system A4 (SEAOC Table 1-G) are used rather than the high values for SMRF systems.